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FAMILIES, HOUSES, AND THE DEMAND FOR ENERGY

Kevin Neels

HOUSING ASSISTANCE SUPPLY EXPERIMENT

A RAND NOTE

This Note was prepared for the Office of Policy Development and Research, U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, under Contract No. H-1789. Its views and conclusions do not necessarily reflect the opinions or policies of the sponsoring agency.

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PREFACE

This note was prepared for the session on Housing Market Behavior at the 26th North American Meetings of the Regional Science Association, held in Los Angeles 9-11 November 1979. It draws on research conducted as part of the Housing Assistance Supply Experiment (HASE), sponsored and funded by the Office of Policy Development and Research, U.S. Department of Housing and Urban Development, under Contract H-1789.

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SUMMARY

There are three ways in which the energy requirements of the existing housing stock can be reduced: changing the way that landlords, tenants, and homeowners operate housing; modifying existing housing to make it more energy-efficient; and replacing existing housing with new housing that is more energy-efficient. Analysis of patterns of energy use in two north central metropolitan areas shows the magnitude of the changes that are possible through each of these three approaches.

Although the owners or occupants of a dwelling could in principle reduce its energy consumption substantially, they are not inclined to do so. The results of the study indicate that if the physical characteristics of the housing stock are held constant, a 20 percent increase in the real price of energy would reduce its use in the residential sector by only about 2 percent. In contrast, modifications to the existing stock of housing have a much greater effect. Installing insulation, for example, would reduce energy use by about 10 percent. The greatest effect can be achieved by replacing existing housing with newly constructed dwellings built to different standards. Replacing single-family units with multiple dwellings of the same size would reduce total energy use per dwelling by nearly half.

As a way of reducing residential energy use, constructing new, more energy-efficient dwellings is both the most effective in the long run and the slowest to yield energy savings. Replacing a significant portion of the housing stock takes decades. For energy savings with little delay, modification of the existing stock is more promising.

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CONTENTS

I. INTRODUCTION

Since 1973, energy prices in the U.S. have nearly tripled, and sudden temporary fuel shortages have become common. Unreliable foreign sources of oil, the arbitrary pricing policies of foreign producers, and the gradual decline of known U.S. reserves have emphasized the importance of energy conservation to stretch domestic supplies and reduce our dependence on imported fuels.

Much of the debate about energy conservation has concerned the residential sector. About one-fifth of all energy consumed in the U.S. is used for residential purposes: heating, cooking, lighting, and operating appliances. Consequently, even a modest reduction in residential consumption would help alleviate the nation's energy problems.

Well-designed policies to improve the efficiency of the residential sector's use of energy must be based on a detailed understanding of the determinants of residential energy consumption. This report offers some important new evidence toward that end by analyzing the determinants of total energy consumption at the level of the individual residential property. Taking into account all forms of energy use allows us to remove the effects of substituting one fuel for another and to identify the factors affecting overall energy efficiency. By examining data on each property and household, we are able to separate the effects of variables pertaining to the household itself, such as its size or income, from the effects of the dwelling's structural characteristics and equipment. The results fill a number of gaps in our understanding of residential energy demand, as explained below.

Most of the previous studies of residential energy use consider only a single fuel. Many have examined the demand for electricity (see Taylor, 1975, for a review of this literature). A smaller number have looked at the consumption of natural gas (Balestra and Nerlove, 1966; Block, 1980). However, many homes use more than one form of energy--for instance, oil for space heating, gas for cooking, and electricity for lighting. In many applications, it is possible to substitute one fuel for another. Gas or electricity, for example, can be used for space heating, water heating, or cooking. Single-fuel studies are inherently incapable of measuring the potential for residential energy conservation because they ignore this fact, confusing reductions in demand due to decreases in overall energy use with those that reflect a switch to other fuels.

Only a small number of studies have investigated total residential energy demand.* Nearly all, however, rely on consumption data aggregated at either the state or national level, which can be related only to similarly aggregated descriptors of the consuming population and their dwellings. Furthermore, they have concentrated on the aggregate, long-run consumption changes associated with increases in fuel prices and income. Such studies have implicitly assumed that the demand for energy is primarily determined by the characteristics of the families using it; they have not been able to test hypotheses about the savings that might be obtained by redesigning the dwellings themselves.

The study reported here uses data from the Housing Assistance Supply Experiment conducted by Rand in Brown County, Wisconsin, and St. Joseph County, Indiana. In the course of the experiment, the owners and occupants of dwellings were interviewed annually for four years, 1974-77 for Brown County and 1975-78 for St. Joseph County. These years span the largest change in energy prices we have experienced in this century. The record for each dwelling includes detailed descriptions of both the occupants and the dwelling itself, estimates of annual expenses for each purchased fuel, and an account of how each fuel was used.

By controlling for the effects of both household and dwelling characteristics, we find that the attributes of the dwelling account for most of the observed variation in energy consumption. If housing

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*The results of one of the earliest attempts to examine the determinants of total energy use are contained in Strout (1961). An investigation of the demand for space heating energy that covers the use of gas, coal, and fuel oil is described in Nelson (1975). In one of the most elaborate studies to date, Baughman and Joskow (1976) analyze the determinants of total energy use in the residential sector and of its allocation among different energy sources. However, none of these studies examines the relationship between energy use and the characteristics of housing stock.

attributes are held constant, energy prices, income, and other family characteristics have only a relatively modest effect on energy use.

The results indicate that energy consumption per dwelling could be reduced over the long run by 20 to 50 percent by substituting fuel-efficient multiple-family dwellings for single-family residential structures. Altering existing dwellings could save 5 to 10 percent, and could be done sooner. Modifications in household behavior would probably reduce energy use by only 2 to 5 percent. Because the time and money costs of saving energy by each approach vary directly with the prospective saving, it is not clear from our study which method is most desirable. Undoubtedly an effort balanced along all three dimensions will ultimately be required to achieve a substantial and timely reduction in residential energy consumption.

The following section outlines our model of residential energy use. The next two sections describe the sources of data and the estimation procedures used in fitting the model. A fifth section presents our findings. The final section discusses the policy implications of the study.

II. THE MODEL

Most previous investigations of residential energy use have started from the assumption that household behavior largely determines the level of energy consumption. This study takes a different position, namely that after a family chooses a given residence, its energy consumption is primarily determined by the dwelling's physical characteristics such as size, the thermal integrity of its walls, and the number and type of appliances in it. The quantity of energy used to operate a particular house is nearly the same regardless of who lives in it. Household behavior regarding thermostat settings, the opening of doors and windows, and the use of hot water affects energy consumption only marginally.

In order to identify accurately the determinants of residential energy use, we considered not only the price of energy and household size and income, but also the characteristics of the building. Studying both sets of factors made it possible to assess their relative importance. A logarithmic transformation of the dependent and most independent variables allowed us to observe their interaction and how that interaction explains total residential energy use.

First among the physical variables included in the model was a set of dummy variables identifying the number of units in each building. Single-family homes use more energy than multifamily units because the former have a higher ratio of surface area to volume. Other factors being equal, the more units there are in a building, the less energy is required per unit to maintain a given interior temperature.

Another set of variables described the quantity of space to be heated. Space was measured by number of rooms in the dwelling and average number of square feet per room.

A third set dealt with the basic thermal integrity of the structure. Because the price of electricity is so high relative to that of gas, electricity competes successfully as an energy source for space heating only in very heavily insulated buildings. A dummy variable identifying electrically heated homes served as a indicator of well-insulated walls and attics.* A second dummy variable designating houses built of brick or stone stood for the effects of the limited insulation usually found in that type of construction. A third dummy variable indicated whether the building was equipped with a complete set of storm windows.

A fourth set of physical variables pinpointed households' use of hot water. The average number of bathrooms per unit on each property measured in part the opportunities for lavish consumption of hot water. A rating of faucets, sinks, and drains, supplied by occupants, described the plumbing conditions in each building. Leaky faucets result in greater use of hot water, and hence higher energy use.

Two other variables were included among the physical characteristics of housing. One, defined as the total 1976 purchase price of all major appliances (the stock) contained in an average dwelling,** represented the effects of household appliances on energy use. The other identified farms, thereby incorporating the energy requirements of shops, barns, and outbuildings.

Despite such careful description, it is usually impossible to establish a direct causal relationship between physical variable and function. Bathrooms, for example, make it easier to use a lot of hot water, but also add more space to be heated. All appliances consume energy directly; washers use hot water, too. Stoves, refrigerators, and dryers reduce the load on the furnace by pumping extra heat into living spaces. The model was intended to capture the overall interaction of various factors rather than to explain the workings of particular portions of the residential energy system.

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*An examination of electrically heated properties by age revealed that most were built in the 1960s during the heyday of the all-electric home, and were very well insulated. The age distribution was bimodal, however. The secondary concentration occurred among buildings erected around the turn of the century. These properties had apparently undergone some type of renovation that included replacement of the original heating system. Electric heating was probably chosen because it cost less to install, which helped to offset its higher operating cost.

**The appliances included in this measure were stoves, refrigerators, dishwashers, disposals, airconditioners, washers, and dryers.

A shorter list of variables described the effects of household characteristics on energy use. Household income and the price of residential energy measured the direct effects of economic factors.* Household size stood for, among other things, the effects of variation in the numbers of showers and loads of wash run through the system. The number of nonworkers in the household indicated how many people were at home during the day; if there were none, the household would be able to save energy by turning the thermostat back for those hours when no one was there. To measure the effects of differences in habits and/or tastes, dummy variables distinguished homeowners and households with elderly heads.

Since variation in weather also has a marked effect on the amount of energy consumed in any given year, the log of the number of heating degree days in each year of observation was the last variable included in the model.

*Prices and income were measured relative to the Consumer Price Index.

III. DATA SOURCES

The empirical results presented below were based upon data collected as part of the Housing Assistance Supply Experiment (HASE), a large-scale social experiment conducted in two north central metropolitan areas: Brown County, Wisconsin (whose central city is Green Bay); and St. Joseph County, Indiana (whose central city is South Bend). The purpose of the experiment was to test the feasibility of a housing allowance program as an instrument of housing policy.* However, the data collected as part of the experiment are sufficient to support a much broader range of analyses.

The HASE surveys were administered annually to stratified random samples of residential properties in the two sites. The first wave of surveys in Brown County was administered during the winter of 1973-74 and gathered information pertaining to the calendar year 1973. The experiment in St. Joseph County started later; the first wave of surveys there was administered during the winter of 1974-75. From these first samples, panels of residential properties were selected for follow-up analysis, and were resurveyed in each of the three subsequent years. In order to keep the samples representative of the current housing stock, each panel was augmented yearly with a random sample of newly constructed properties. The result was a rich set of data describing both cross-sectional and longitudinal differences in behavior.**

For rented dwellings, both landlords and tenants were contacted. The landlords supplied a complete accounting of the revenues and expenses associated with each property, a description of the property's physical characteristics, and a listing of all repairs made over the preceding year. Tenants supplied demographic and socioeconomic

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*The Supply Experiment was so named because it was designed to measure the market response to the housing allowance program. The direct effects of the subsidies on demand were examined in the Demand Experiment (see Kennedy, 1980, for a summary of the results of that study).

**For a more comprehensive description of the HASE survey effort see Lowry (1980).

information. They also provided a description of the condition of each dwelling and its interior, including the number of rooms and bathrooms, and the number and type of appliances present. In addition, where tenants paid for utilities directly, they supplied estimates of average monthly bills.

Since homeowners combine the roles of owner and occupant, it was possible to collect similar information about their properties in a single survey.

Trained fieldworkers examined the buildings located on both rental and homeowner properties. They noted the principal construction materials as well as the condition of various portions of the building exteriors. Information on the number of square feet of space in the buildings was obtained from public records in the two counties.

The unit of observation for the analysis was a residential property. However, to make the results easier to interpret, energy use was expressed on a per dwelling basis. Those variables obtained from the tenant surveys describing household characteristics and the interiors of the dwellings were constructed by averaging across the units on each property.*

Four years (1973-76) of data in Brown County were combined with two years (1974-75) of data from St. Joseph County.** The panel nature of the data permitted multiple observations for each property. The pooling of data from both counties was important for the derivation of some results. Between 1973 and 1976 energy prices increased steadily, as did the severity of the winters. Those variables showed similar trends in both locations. There was little difference between the sites in energy prices. In St. Joseph County (the more southern site), however, the winters were somewhat milder. Pooling the data broke the

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*In aggregating the data in this way a certain amount of information is inevitably lost. Units on a single property tend to be very similar, however, and hence also tend to be inhabited by similar households. The amount of information lost through aggregation is therefore likely to be small.

**Two additional years of data were collected in St. Joseph County but, at the time of this research, were not yet available.

collinearity between price and weather and made it possible to distinguish the effects of each variable.

The data contained estimates of expenditures by tenants, landlords, and homeowners for four forms of residential energy: electricity, natural gas, fuel oil, and coal.* However, because the use of coal in both counties was extremely limited, this study examined the factors determining usage of the other three energy sources only.

Conversion of expenditures to physical units of energy was based on fuel prices in the two counties. For fuel oil, total expenditures were divided by the price of fuel oil per gallon delivered. Because electricity and natural gas were billed according to complex declining block rate structures, a more complicated procedure was required. First, the basic rate structures as well as all fixed fees, surcharges, and purchased fuel adjustments were combined in order to estimate average rates throughout the year. The average monthly bill for each property was then worked backwards through the rate structure to arrive at an estimate of average monthly energy use. Adding together the amounts billed to the tenant and the landlord yielded total fuel use on rental properties. Energy use on homeowners' properties was computed from the homeowners' fuel expenditures.

All three forms of energy were converted to equivalent units and then combined into a single measure. The conversion was based upon the heat content and potential efficiency of each kind of energy. When electricity is used very little of it is wasted, but 30 percent of the heat content of fuel oil or natural gas is normally lost through the venting of exhaust gases; such routine waste was taken into account.** Total energy use was measured in millions of usable BTU's per month.

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*For large properties where only a sample of occupant households was interviewed, total energy expenditures were estimated by multiplying the sum of the reported energy expenditures by the inverse of the fraction of the total rent roll for the property represented by the surveyed units. This procedure is based on the assumption that among the units on a particular property energy consumption is directly proportional to contract rent.

**The 30 percent waste factor overstates the efficiency of fuel oil and natural gas as sources of space heat. In typical heating

Price was measured by a weighted average of total costs per household for typical quantities of each fuel, which yielded an average rather than a marginal price.* The costs of purchasing typical amounts of all three fuels were computed, and then weighted together using data on average Brown County levels of energy consumption. The resulting price measure varied mostly over time; it also varied slightly cross-sectionally, partly because of minor price differences between the counties and partly because of intra-site price variation.** Dividing this nominal price measure by the national Consumer Price Index provided a measure of real prices.***

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systems roughly 20 to 25 percent of the heat content of the fuel will be lost through the venting of exhaust gases, and another 25 percent will be lost in the distribution system (See Lokmanhekim, 1974). In contrast, the end-use efficiency of electrical resistance heating will be nearly 100 percent. The heat loss from a gas water heater because of the venting of exhaust gases will again be 20 to 25 percent. The distribution losses of gas and electric systems, however, will be identical. For practical reasons it was impossible to apply efficiency adjustments to gas and oil which varied by function. An efficiency factor appropriate for water heaters was chosen because water heating (along with cooking) was the function for which gas and electricity were most directly in competition. Both Baughman and Joskow (1976) and Chern (1978) found in their studies of residential energy demand that their results were insensitive to the choice of efficiency factor over a range from 0.3 to 0.8.

*As Taylor (1975) has pointed out, the marginal price would theoretically have been preferable here. Attempts to implement this suggestion, however, ran into a host of problems, not the least of which was the question of which fuels were being used at the margin. All properties used at least two fuels, except for those heated electrically. The option of using an "average" marginal price was rejected as being too poor an approximation to the theoretically correct price. Overall it seemed safer to use the average price which, though less than ideal, was at least well defined and familiar in the literature.

**In Brown County both gas and electric rates were higher in rural than in urban areas. In St. Joseph County the existence of a municipal utility in the suburban city of Mishawaka resulted in somewhat lower electricity rates there.

***An effort was made to test for differences between the two sites in the level of consumer prices. However, for a variety of offsetting reasons price levels in the two sites at any one point in time were found to be nearly identical. For a summary of the research leading to this conclusion see Neels (1979).

IV. ESTIMATION METHODS

Pooling of time series and cross-sectional data can lead to statistical problems. In the present instance unobserved housing attributes that cause a property to display unusually high or low energy use are likely to set in motion effects which persist over time. A property consuming an unusually high amount of energy in one year is likely to do so in other years as well, leading to a correlation between the error terms for successive observations on the same property. Such correlation decreases the efficiency of OLS coefficient estimates and produces inconsistent estimates of coefficient standard errors.

The use of a variance components model dealt with the problem of correlation between error terms. Within this model it was assumed that the error term for the regression equation could be divided into two components, one of which was specific to a residential property while the other varied over both properties and years. The model can be represented symbolically as follows:

$$Y_{it} = \alpha_o + \alpha_i X^1_{it} + \ . \ . \ . + \alpha_n X^n_{it} + u_t + e_{it}$$

where Y_{it} is energy use per unit for property i in year t; X^1_{it}, . . ., X^n_{it} are the independent variables; u_i is the residual error component for property i; and e_{it} is the residual error component for property i in year t.

If u_i and e_{it} are independently and normally distributed the error covariance matrix which results is block diagonal. Each block corresponds to a cluster of observations on a particular residential property. Within each block the elements on the main diagonal are equal to 1 while the off-diagonal elements are equal to the coefficient measuring the correlation between residuals for different observations on the same property. This correlation was constant and independent

Table 1

ENERGY USE REGRESSION RESULTS

Variable	Sample Mean	Coefficient	t-Statistic
Presence of single-unit building	.751	.713	6.77
Presence of two-unit building	.206	.546	5.19
Presence of three-unit building	.023	.374	3.16
Presence of four-unit building	.013	.141	1.10
Log of rooms per unit	1.613	.484	11.29
Log of floor space per room	5.108	.172	6.30
Presence of brick or stone construction	.065	.061	1.70
Presence of complete storm windows	.828	-.032	-1.34
Presence of electric space heat	.014	-.334	-4.36
Log of 1+ bathrooms per unit	.728	.185	2.66
Presence of working faucets and drains	.825	-.041	-1.76
Appliance stock[a]	1172	.000107	3.31
Presence of farming operation	.042	.178	3.95
Log of real price of energy	-.199	-.113	-0.93
Log of real occupant income	8.637	.001	0.12
Log of 1+ number of nonworkers	.948	.025	1.04
Log of 1+ household size	1.360	.108	2.70
Presence of elderly household head	.123	-.041	-1.28
Presence of homeowner household	.371	-.035	-1.53
Log of heating degree days	8.901	.933	10.62
(Constant)	--	-8.46	-10.39

SOURCE: Tabulated by author from 3,108 records of landlord, household, and residential building surveys conducted in Brown County, Wisconsin, and St. Joseph County, Indiana.

NOTE: RSQR = .24.

[a]Entered without log transformation.

of properties without a complete set of storm windows. Most dwellings in both counties have at least some storm windows, but no clear distinction was made between an almost complete set, some, almost none, or none at all. The variable's coefficient measures only the average effect of completing the set. Finally, if the presence of electric heat served as a proxy for the amount of insulation present, then complete insulation appears to have a powerful effect on energy use.*

The physical determinants of hot water use have the expected effect on total energy consumption. The data indicate that a two-bathroom unit used 8 percent more energy than an otherwise comparable one-bathroom unit. The condition of the plumbing system also has a measurable effect. Properties whose faucets, sinks, and drains were all working properly used 4 percent less energy than those whose equipment was faulty.

The effect of appliance stock on energy use is completely in accord with the results reported by other studies (see Houthakker, 1951; Wilder and Willenborg, 1975; and Acton, Mitchell, and Mowill, 1976). The more appliances present on the property, the greater the amount of energy used. The effect is highly significant.

Of less general interest is the finding that farms used 19 percent more energy than normal residential properties. This result is in accord with a priori expectations.

HOUSEHOLD CHARACTERISTICS

Past estimates of the price elasticity of demand for energy have often confused the impact on energy consumption of altering dwellings with the effects of variations in household energy-using behavior. Since the model controlled for the effects of dwelling characteristics, its measure of the effect of price on energy use reflects behavior alone. At -0.11, our point estimate for the short-run price elasticity of demand for energy falls within the range of estimates

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*It is likely that the estimated coefficient for the presence of electric heat overstates the effect of insulation somewhat, for reasons discussed above in connection with the choice of efficiency factors for gas and fuel oil.

contained in other literature.* The standard error of the estimate for this coefficient is very high, however. The data are statistically consistent with the hypothesis that once the physical characteristics of the housing stock are accounted for, there is no relationship between price and energy use. Still, it is difficult to say whether the relationship is lacking because price really has no effect on energy use in the short run, or because the data do not contain enough variation in price to measure the effect precisely.

The estimated income elasticity of demand for energy is extremely small and not significantly different from zero. Although that result stands in sharp contrast with earlier studies (see Strout, 1961; Baughman and Joskow, 1976; and Chern, 1978), none of the others controlled for the effects of dwelling unit characteristics as was done here. Previous estimates of the income elasticity of energy demand may more accurately be described as estimates of the income elasticity of demand for housing. As households become richer, they usually want more rooms, bathrooms, and appliances, and are more likely to occupy single-family homes. After the type of housing has been taken into account, income appears to have very little influence on the intensity of use of the dwelling's appliances and mechanical systems.

The estimated coefficient for the number of nonworkers per household indicates that the addition of one nonworker to a household would increase energy use by almost 2 percent. Statistically, however, the effect is very weak. The t-statistic is barely over 1 in absolute value.

The one strong performer among the household variables is that measuring household size. Its coefficient is clearly different from zero. Even so, the real impact is slight. A household with three people would use only a little over 3 percent more energy than one composed of two persons.

There does appear to be a certain amount of variation in energy use per unit related to taste and life-style. When all other physical and household characteristics are held constant, elderly households

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*Baughman and Joskow (1976), for example, estimate it to be -0.08.

use roughly 4 percent less energy than nonelderly households. This could be the result of energy-saving habits acquired much earlier in life. Elderly households may, for example, be more careful about setting the thermostat back at night or when they leave the house,* or they may be more likely to close off unneeded rooms.

Homeowner households use about 3.5 percent less energy than comparable renter households, possibly reflecting more careful operation by owners. Alternatively, homeowners may spend more on maintenance; consequently, their houses may be more energy-efficient in ways not captured by the variables in the model.

It appears from these results that the amount of energy it takes to run a house has very little to do with the household that occupies it. In fact, since household characteristics do not seem to make a difference, the inference can be drawn that behavior regarding the use of energy does not matter either. To claim that families have no control over their energy consumption would be to overstate the case, however. Reducing thermostat settings and closing off rooms will clearly have some effect on heating-fuel use. To have a major effect, though, would require such extensive changes in life-style that families are apparently unwilling to make them, even in the face of large increases in the price of energy.** The net result is that while it is technically possible for families to affect energy use by altering their behavior, in practice they do not.

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*In the first third of this century coal was used as a major source of residential heat. To keep the coal fire burning through the night it was necessary to stoke and damp down the furnace every night before retiring. Such a habit might lead in later life to the consistent practice of setting the thermostat back at night.

**Quentzel (1976) found that setting a thermostat back to 65 degrees every night reduced heating fuel consumption in a test house by less than 10 percent. The proportionate reduction in total energy use would have been even smaller. Moreover, that saving depended on perfect thermostat setting behavior, which Quentzel emphasized would be difficult to attain without the use of automatic equipment such as a clock thermostat.

VI. POLICY IMPLICATIONS

In evaluating the effectiveness of alternative approaches for encouraging energy conservation in the residential sector, the government must consider cost, the amount of energy saved, and the length of time required for policies to take effect. All else being equal, the most desirable approach is the one which brings about the greatest reduction in energy use. If alternative forms of intervention are likely to have similar costs and results, the most effective is that which takes effect most quickly.

In terms of potential energy savings, this study provides strong evidence in favor of policies aimed at changing the characteristics of the housing stock, rather than those designed to change the characteristics or life-style of households. As we have seen, who occupies a house has a relatively minor effect on how much energy is used. Households appear to affect energy use only within relatively narrow limits that are determined by the design and construction of the unit and building.

The energy-consuming characteristics of the housing stock can be changed either by replacing existing structures or by altering them: The two procedures differ greatly as to capital cost and how long it would take for their effects to be felt.

In the long run, the most effective policies are those affecting new housing design. The study indicates that consolidating dwellings into structures with five or more units would cut energy use nearly in half relative to single-family homes. The regression results point to a high payoff in energy savings from shrinking the amount of space to be heated as well. Building four-room rather than five-room dwellings would lower consumption by more than 10 percent. Installing extensive insulation, which is usually feasible only at the time of construction, could lead to energy savings of up to 20 percent.* Emphasizing new

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*This figure was derived from the electrically heated home coefficient. Recall that the dependent variable for the analysis was the log of *usable* energy per unit. For fuel oil and natural gas usable construction in locations with warmer climates would also reduce residential energy consumption. Over the period examined, a typical house in South Bend used 20 percent less energy than a comparable house in Green Bay. In Philadelphia, that same house would use 35 percent less energy than one in Green Bay.*

The potential effects of modifying existing housing are more modest. Installing insulation in existing homes is more difficult than doing so in buildings under construction. The effects of insulating readily accessible portions of an existing house might roughly be estimated to reduce energy use by about 10 percent. A complete set of storm windows would account for 3 percent less energy used per unit. If the dwelling initially had no storm windows at all, adding them would undoubtedly make a much greater difference--possibly in the

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energy was computed by multiplying the raw quantities of the two fuels by their respective heat contents and then by an efficiency factor measuring various forms of energy loss. Ideally, that factor should have varied according to the function for which the fuel was used, but this proved impossible. Instead, a compromise was made, and a single factor was used, which probably overstated the efficiency of fossil fuel heating systems and overestimated the quantities of usable energy in gas and oil heated homes. This single factor also led to an overestimation of the difference in energy use between fossil fuel and electric heating systems. The magnitude of the overestimation should be in the neighborhood of 25 percent, the amount of energy lost in the distribution portion of a typical fossil fuel heating system (see Lokmanhekim, 1974). Applying the corrected loss to the estimated differential of 28 percent between fossil fuel and electrically heated units reduces the difference to roughly 20 percent. This is obviously a crude estimate, but it is in the same neighborhood as the estimate in Keyes (1976) of from 11 to 29 percent.

*In practice it is highly doubtful that identical houses would be built in Green Bay and Philadelphia. Identical houses would have too much insulation for Philadelphia or too little for Green Bay. Hutchins and Hirst (1979) showed that the optimal amount of insulation for a structure depends upon the severity of the climate in which it will be located. Because of this, as Nelson (1975) observed, the relationship between weather and energy use is somewhat weaker from one section of the country to another than it is longitudinally for a single area. The estimates of climate-related variations in energy use in the text are therefore probably somewhat high, but the error is not enough to affect the integrity of the argument.

neighborhood of 5 percent.* Overhauling a faulty plumbing system would save another 4 percent.

Trying to bring about changes in households and their operation of energy-using equipment would be even less effective than altering existing housing. The fact that elderly households operate their property more carefully results in an energy savings of 4 percent. That figure suggests what magnitude of savings could realistically be expected from household conservation in general.

It appears that if the characteristics of the house are held constant, changes in the price of energy have relatively little effect on consumption. A 20 percent increase in the real price of residential energy would reduce energy use in the short run by an estimated 2 percent. This seems to contradict the findings of other studies, but the conflict may be more apparent than real. While energy price may well exert only a limited influence on household behavior regarding thermostat settings or appliance use, it is likely to be a critically important factor in decisions to alter the characteristics of the housing stock in ways that will improve its energy efficiency. Viewed from this perspective, price will undoubtedly continue to be an important instrument of energy policy.

In terms of immediate payoff, the three approaches have a reverse order of impact. Changes in household habits would produce the quickest savings in residential energy use. Thermostats in every dwelling, for example, can be set back at once. Alterations of existing housing take longer. The capacity of the repair and rehabilitation industries determines the rate at which storm windows and insulation can be installed. The normal rate at which existing stock is replaced limits even more severely the scope of policies aimed at new housing. Between 1973 and 1977, dwellings were lost through demolition or disaster at the rate of 270,000 per year and added through new construction at the rate of

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*This estimate assumes that the effect of completing a partial set of storm windows is, on average, half that of installing storm windows where none previously existed. The survey data indicated that of the properties lacking a complete set of storm windows, roughly three-quarters had at least some.

1,943,000 (U.S. Department of Commerce, 1979, Table A). At that speed, and starting from the 1977 stock of 82 million units, it would be almost 40 years before half of the housing stock was composed of new, more energy-efficient units.

The cost of implementing each of the three approaches is harder to evaluate, because it depends on particular technical circumstances that are likely to vary from one place to another and even from one house to another. However, it is safe to say that feasible changes in household behavior, slight as they might prove to be in impact, would be the cheapest to bring about. Whether larger effects could be achieved is hard to predict, but a campaign aimed at doing so would no doubt be quite costly. Retrofitting existing housing and upgrading new construction are both more expensive and slower to implement relative to what is practical in terms of household behavior; but the benefits are correspondingly greater.

The logical conclusion is that all three policy alternatives will probably play a role in residential energy conservation. Behavior-oriented policies are important because of their immediate payoffs. Policies which seek to encourage the alteration of existing housing, as well as those which affect the way in which new housing is designed and built, will take more time to implement, but will eventually have a greater effect. But the ultimate reward from physical changes in the stock will be substantial enough to justify the long period of time needed to bring them about.

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